

# **Evanescent Acoustic Wave Scattering by Targets and Diffraction by Ripples**

PI name: Philip L. Marston

Physics Department, Washington State University, Pullman, WA 99164-2814

Phone: (509) 335-5343 Fax: (509) 335-7816 Email: [marston@wsu.edu](mailto:marston@wsu.edu)

Co-PI: Curtis F. Osterhoudt

Physics Department, Washington State University, Pullman, WA 99164-2814

Phone: (509) 335-4946 Fax: (509) 335-7816 Email: [gardyloo@mail.wsu.edu](mailto:gardyloo@mail.wsu.edu)

Award Number: N000140310262

<http://134.121.46.58/Research/acoustics.htm>

## **LONG-TERM GOALS**

The goal is to develop and test certain ideas relevant to the coupling of sound with small targets buried in the ocean bottom. This is a “Graduate Traineeship Award” in Ocean Acoustics.

## **OBJECTIVES**

The main objective is to understand consequences of incident wave evanescence on (existing or under-utilized) scattering observables. It is also planned to explore conditions whereby surface roughness enhances the coupling of sound to simulated buried targets. Resolving these issues should be helpful for discriminating between echoes from real buried targets and background objects.

## **APPROACH**

Simulation experiments will be carried out and the results will be compared with theoretical predictions. Professor Philip L. Marston directs the research (while receiving no financial support from this grant). Curtis F. Osterhoudt is a graduate student supported by this grant at Washington State University.

## **WORK COMPLETED**

We previously identified an environmentally-friendly liquid mixture that, when placed in contact with water, has the desirable acoustic contrast to facilitate the production of acoustic evanescent waves in a liquid having a substantial volume. The mixture does not mix with water and is denser than water and typically has a speed of sound of 885 m/s. The emphasis in FY-2006 has been to continue scattering experiments with a system containing approximately 70 gallons of the dense liquid surrounded by a 3000 gallon water tank. This system was used to generate wavefields having significant evanescent components by illuminating the interface with a beam having post-critical incidence. The source transducer is placed in the dense liquid mixture, which simulates the ocean water column. The water in the tank above the mixture simulates the ocean bottom. Hydrophones to detect and measure scattering may be placed either in the water (the simulated bottom) or in the mixture (the simulated water column). In the annual report for FY-2005 [1] we demonstrated that several detailed features of the generated wavefield were in agreement with calculations from a wavenumber-based simulation.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>30 SEP 2006</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2006 to 00-00-2006</b>	
4. TITLE AND SUBTITLE <b>Evanescent Acoustic Wave Scattering by Targets and Diffraction by Ripples</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Washington State University, Physics Department, Pullman, WA, 99164-2814</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>5</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

That research was presented by Osterhoudt at the October 2005 ASA meeting [2]. Elsewhere we described how resonances of small hollow water-filled cylinders could be excited by using evanescent wave tone bursts having an appropriate frequency [3,4]. The emphasis this year was on the characterization of the response of such targets as a function of the position and orientation of the target. The emphasis of this work has been on understanding how evanescent waves couple to the low frequency modes of targets and how the resulting radiation reaches the receiver. This emphasis is relevant to interpreting the response of buried targets at low frequencies.

## RESULTS

The evanescent wavefield decays upward in the water since the simulated water column (the oil) is slightly denser than (and is trapped below) the simulated ocean bottom (the water). This is a convenient arrangement since it allows hydrophones and target positions to be easily scanned within the simulated bottom. As an example of the detailed features visible in the scattering records, Figure 1 shows the signal received by the sending transducer in a representative backscattering measurement where the frequency of the incident tone burst (63.97 kHz) is adjusted to strongly excite the lowest organ-pipe resonance of a small horizontal water-filled stainless steel cylindrical shell. The initial build up is followed by a gradual decay (or ring-down) of the excited target mode. As shown in the figure the target's response depends on how far the cylinder is from the interface. We have also found that the response depends on the orientation in a way describable by an approximate model [4,5,6,7]. The length and outside diameter of the cylinder are 10.4 mm and 2.1 mm.

It has been possible to detect how the quality factor or "Q" of the excited mode depends on the distance between the target and the interface. The time it takes for the mode to ring down is proportional to Q and the frequency-width of the resonance is inversely proportional to Q. Radiation from the target reflects from the interface and the phase of that reflection arriving back at the target location affects the Q. Let the wavelength of the radiation in the simulated sediment (the water) be denoted by  $\lambda$ , which for the mode in Figure 1 is 24 mm. It is predicted that a shift in the distance  $z$  of the target from the interface by approximately  $\lambda/4 = 6$  mm will shift a maximum in the Q to a minimum. Figure 2 shows the measured variation in the Q with distance  $z$  of the target from the interface (within a small systematic uncertainty). As predicted, a variation in the Q is observed and the spacing between the maximum and the minimum in the Q is close to the approximate predicted value of 6 mm. When the cylinder is close to the interface the monopole-like source at each end of the cylinder becomes partially dipole-like which decreases the cylinder's radiation efficiency and raises the Q of the mode.

These observations were with a flat interface. Osterhoudt has also demonstrated an electrical method for exciting ripples on the interface between the two liquids however it is unlikely that it will be possible to make scattering measurements with ripples present during the tenure of this grant.

## IMPACT/APPLICATIONS

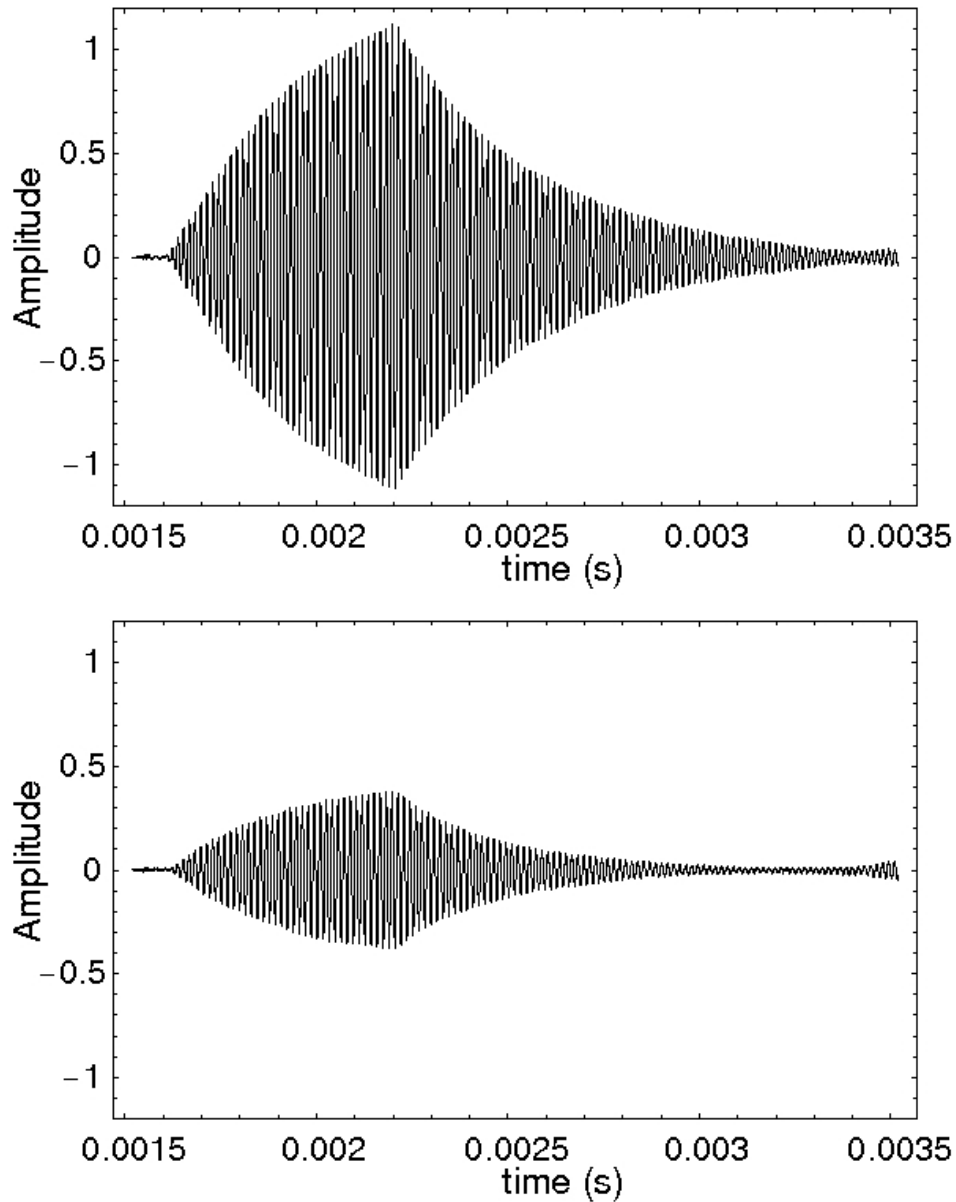
This research should eventually improve the understanding of the acoustic signatures of buried targets and the acoustic discrimination of target and background acoustic scattering. These experiments suggest that in regions where the sediment is smooth it may still be possible to detect certain targets at grazing incidences by relying on the coupling of evanescent waves with low-frequency, high-Q modes of targets.

## **RELATED PROJECTS**

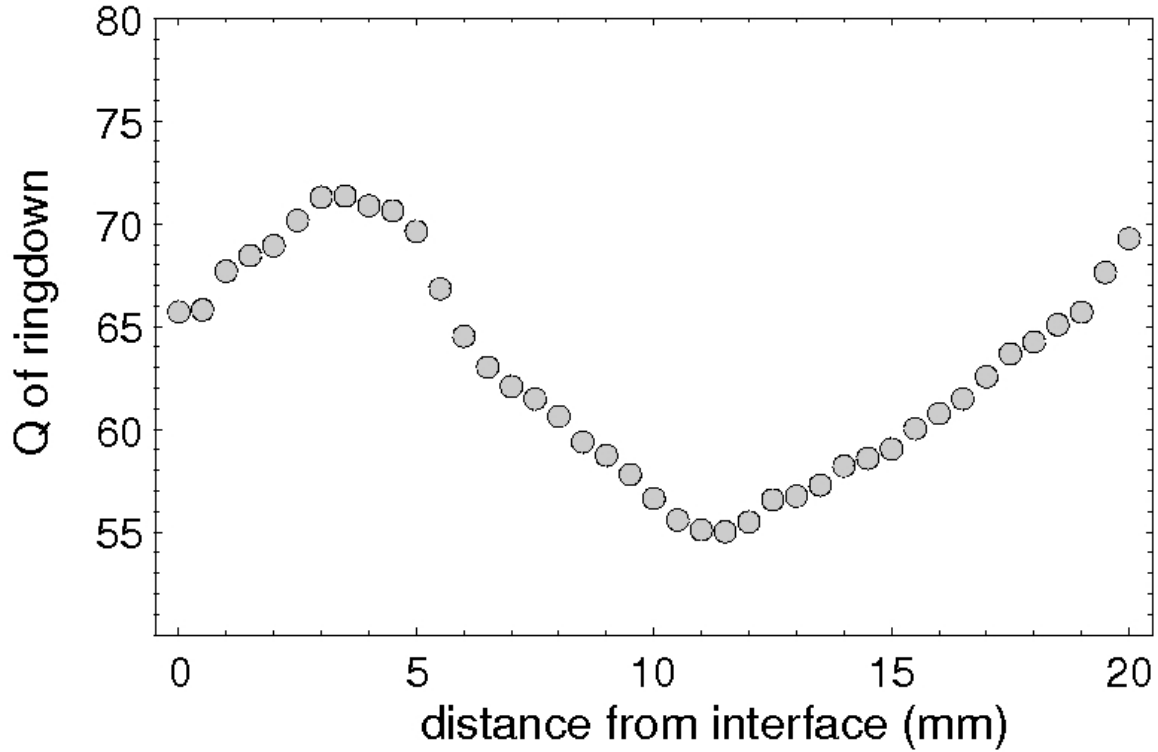
This Graduate Traineeship Award does not cover the significant materials and supplies costs for an experiment of this type. Those costs are covered in part by the following grants from ONR code 32CM: N000140310585, "Scattering of Evanescent Acoustic Waves by Regular and Irregular Objects" and a renewal grant N000140610045. Grant N000140310585 has provided partial support for other students and staff who have assisted with this project. Additional information is provided in the report for that grant. Associate Professor Scot F. Morse (Computer Science Department, Western Oregon University) assisted in aspects of the OASES based simulations with the partial support of ONR SWAMSI grant N000140410075.

## **REFERENCES**

- [1] P. L. Marston & C. F. Osterhoudt, Annual report for grant N000140310262 (2005).
- [2] C. F. Osterhoudt, P. L. Marston, & S. F. Morse, "Wave field and evanescent waves produced by a sound beam incident on a simulated sediment," J. Acoust. Soc. Am. 118, 1970 (A) (2005).
- [3] C. F. Osterhoudt, C. Dudley, D. B. Thiessen, P. L. Marston, & S. F. Morse, "Production of evanescent acoustic waves and their scattering by resonant targets," J. Acoust. Soc. Am. 117, 2483 (A) (2005).
- [4] P. L. Marston, Annual report for grant N000140310585 (September 2005).
- [5] P. L. Marston, Annual report for grant N000140310585 (September 2006).
- [6] C. F. Osterhoudt & P. L. Marston, "Scattering of evanescent waves incident on targets in a simulated sediment," to be presented at the December 2006 ASA meeting.
- [7] C. F. Osterhoudt, Ph.D. thesis in preparation.



**Figure 1. (Upper part):** The signal scattered from the target back to the source when a horizontal water filled cylindrical shell is driven by a 64 kHz evanescent wave. Here, the target's lowest organ-pipe mode is strongly excited, and a ring-up is followed by a gradual decay. The wall of the cylindrical target is 3.5 mm from the oil-water interface that simulates an interface between water and sediment. **(Lower part):** This is the same situation as shown in the upper figure; however, the wall of the cylindrical target is now 11 mm from the interface, and the mode is not so strongly excited because of the evanescence of the incident wave. Measurements of the decay rate of the decaying part of the echo show that the decay is more rapid than in the upper figure.



**Figure 2.** The measured variation in the quality-factor ( $Q$ ) of the decaying oscillations of the target. The highest  $Q$  shown here occurs when the wall of the cylinder is 3.5 mm from the interface (corresponding to the upper record shown in Figure 1), and the lowest  $Q$  occurs when the wall of the cylinder is 11 mm from the interface (the lower record in Figure 1). The  $Q$  values were extracted from the traces using an algorithm that numerically fits the decaying portions to a sine function with an exponentially-decaying envelope. The modulation is a consequence of the reflection of the scattered wave from the interface back to the target.